Final Report
for the
Scripps Institution of Oceanography
University Research Initiative (URI)
entitled
"SCRIPPS OCEAN MODELING AND REMOTE SENSING (SOMARS)"

ONR Contract No. N00014-86-K-0752

Co-Principal Investigators:

James J. Simpson
Geoffrey K. Vallis
Warren B. White

10 April 1990

INTRODUCTION

This is the Final Summary Report of the Scripps Institution of Oceanography University Research Initiative (URI) entitled "*Scripps Ocean Modeling and Remote Sensing* (SOMARS)" [ONR Contract number N00014-86-K-0752]. The report covers the performance period 1 September 1986 –31 March 1990 and contains a set of unedited technical-financial statements prepared by individual investigators working on the URI. For your convenience, these statements are arranged in alphabetical order and separated by index tabs.

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Final Report

Scripps University Research Initiative

James J. Simpson

I. Scientific Activity

The *in situ*/remote sensing component of the Scripps URI "Scripps Ocean Modeling and Remote Sensing (SOMARS)" concentrated on three activity areas throughout the period of performance of the URI:

A. Integrated System Development
B. Experiments at Sea
C. Coupled analysis of *in situ* data with digital image analysis of remotely-sensed data.

A. Integrated System Development

An integrated seagoing *in situ*/remote sensing system was developed It incorporated a node for full digital image analysis of remotely-sensed data at sea, a node for collecting and processing underway surface data ($f = f(x,y,t)$), and a vertical profiling node for CTD and radiosonde capture. An extensive group of image analysis software also was implemented in UNIX as part of this system development.

B. Experiments at Sea

Three major cruises were conducted during 1987 and 1988 as part of the URI. The first cruise used USNS *De Steiguer*, was done in cooperation with NOSC, consisted of 4 legs for a total of 45 days at sea, and measured the decay sequence of a mesoscale eddy in the offshore California Current. The second cruise was conducted on RV *Sproul* and measured variations in the flow of the California Undercurrent in relation to bathymetric features as well as provided ground truth for GEOSAT tracks. The third cruise also was conducted on RV *Sproul* and observed high-frequency variation in California Undercurrent flow.

C. Analysis of *In Situ* and Remotely-Sensed Data

The objective of this research was to combine various types of *in situ* analysis with remotely-sensed digital image analysis to quantify our understanding of offshore mesoscale eddies in the California Current and the relation of these eddies to instabilities in the California Undercurrent. Listed below are papers which resulted from this analysis.

Lynn, R.J., and J.J. Simpson, 1987: California Current System - The seasonal variability of its physical characteristics. J. Geophys. Res., 92(C12): 12,947-12,966.

Liu, H.-T., J.J. Simpson, and J.C. Schedvin, 1988: A preliminary laboratory study of the lateral entrainment of non-local waters by a subsurface mesoscale eddy. Experiments in Fluids, 6: 217-227.

Simpson, J.J., and R.J. Lynn, 1990: A mesoscale eddy dipole in the offshore California Current. J. Geophys. Res., in press.

Lynn, R.J., and J.J. Simpson, 1990: The flow of the Undercurrent over the Continental Borderland off Southern California. J. Geophys. Res., in press.

Simpson, J.J., and C. Humphrey, 1990: An automated cloud screening algorithm for daytime AVHRR imagery. J. Geophys. Res., in press.

Wahl, D.D., and J.J. Simpson, 1990: Physical processes affecting the objective determination of near-surface velocity from satellite data. J. Geophys. Res., in press.

Eckstein, B.A., and J.J. Simpson, 1990: Aerosol and Rayleigh radiance contributions to Coastal Zone Color Scanner images. Internat. J. Rem. Sens., in press.

Eckstein, B.A., and J.J. Simpson, 1990: Cloud screening Coastal Zone Color Scanner images using Channel 5. Internat. J. Rem. Sens., in press.

Wahl, D.D., and J.J. Simpson, 1990: Satellite derived estimates of the normal and tangential components of near-surface flow. Internat. J. Rem. Sens., submitted.

Simpson, J.J., 1990: On the accurate detection and enhancement of oceanic features observed in satellite data. Remote Sens. Environ., in press.

Simpson, J.J., 1990: Oceanographic and atmospheric applications of spatial statistics and digital image analysis. Chapter in National Research Council's "Panel on Spatial Statistics and Image Processing: A Cross-Disciplinary Report." (To be published in Summer of 1990.)

Simpson, J.J., and J. Bloom: Objective determination of near-surface velocity from spacecraft data using minimum distortion and log search methods. J. Geophys. Res., submitted 1990.

II. Educational Activity

A. Graduate Student Advising

- Mr. Darrin D. Wahl - M.S. in Engineering Science
  (Professional degree, not a terminal masters)
  Thesis Advisor and Chairman of the Committee. Publications:

  Wahl, D.D.: Velocity estimates from space: Sensitivity to computational methods and near-surface physical processes. M.S. Thesis, University of California, San Diego, 161 pp. (1989).

  Wahl, D.D., and J.J. Simpson, 1990: Physical processes affecting the objective determination of near-surface velocity from satellite data. J. Geophys. Res., in press.

  Wahl, D.D., and J.J. Simpson, 1990: Satellite derived estimates of the normal and tangential components of near-surface flow. Internat. J. Rem. Sens., submitted.

- Mr. Timothy Gallaudet - M.S. in Oceanography/Applied Ocean Sciences
  (Naval student; not a terminal M.S. degree)
  Thesis Advisor: Topic will relate to AVHRR analyses of ocean systems.

(II. Educational Activity, Continued)

B. Postdoctoral Research Training

Dr. Barbara A. Eckstein - January 1987 through September 1989

Dr. Eckstein had no previous training in either oceanography or remote sensing when she arrived at SIO. During her PGR appointment she was trained primarily in digital image analysis and remote sensing. This led to two publications:

Eckstein, B.A., and J.J. Simpson, 1990: Aerosol and Rayleigh radiance contributions to Coastal Zone Color Scanner images. Internat. J. Rem. Sens., in press.

Eckstein, B.A., and J.J. Simpson, 1990: Cloud screening Coastal Zone Color Scanner images using Channel 5. Internat. J. Rem. Sens., in press.

III. Cooperation with Navy Labs

A. Naval Ocean Systems Center

A joint cruise was conducted with NOSC on USNS *De Steiguer* for 45 days (14 Feb.-21 March 1987) to observe mesoscale eddy variability in the offshore California Current with Dr. Al Zirino of NOSC.

B. Naval Environmental Prediction and Research Facility (NEPRF)

Dennis Perryman (NEPRF) participated on the Feb.-March 1987 URI cruise. He made radiosonde measurements concurrently with our CTD and meteorological flux measurements. Dennis and I are now working on a manuscript which discusses the atmospheric structure above an offshore mesoscale eddy in the California Current.

IV. Administration

During the entire performance period of the URI, I have served as Secretary of the Executive Committee. As such, I have been the principal liaison between the Executive Committee and UCSD Contracts and Grants, Cal Space Contracts administrative personnel, the ONR Resident Representative Mr. R. Bachman, and ONR Washington. Preparation of reports, budget reviews, individual investigator requests for budgetary reprogramming authority, and the like constituted the major part of this administrative function.

V. Financial Statement

The entire URI funds allocated for my research, as well as all administrative funds, were exhausted as of 31 March 1990.

UNIVERSITY RESEARCH INITIATIVE

Final Report

March 1990

G. K. VALLIS

This brief report summarizes some activity under the Scripps URI. It covers only activity related to modelling work, under the general supervision of G. K. Vallis.

An eddy resolving model of the California Current was developed and used to simulate the mean and eddy conditions of the Eastern North Pacific. The model is nested within a model of the entire North Pacific basin. Nesting techniques were developed and used as appropriate. Preliminary data-assimilation experiments with the model were performed.

An eddy resolving adiabatic primitive equation model of the Eastern North Pacific has been developed. This model is to be used for more realistic simulations of the CCS, and ultimately for data-assimilation experiments.

A new technique was developed for the fast solution of non-separable elliptic equations in irregular domains. The method is based on a combination of the capacitance matrix method and a fast iteration around Poisson's equation. The method is several times faster than previous methods and may be used for a wide variety of problems, in oceanography and in other fields.

The development of both models represents an effort which will continue to bear fruit in the future, both in the actual use of these models and in the use of techniques developed (e.g., nesting, fast solvers) in other situations.

A new technique was developed for construction of stable solutions of the equations of motion, and the method applied to two-dimensional flow. An extension of the technique is currently being studied which shows promise of solving the initialization problem for primitive equation models in irregular domains, namely the problem of artifactually exciting fast waves by the inclusion of unbalanced data.

More details of all these activities may be found in the publications listed. These will be sent to ONR shortly.

A postdoctoral fellow, A. Pares-Sierra, was totally supported and a student. G. Auad, was partially supported on this grant.

Publications in Refereed Journals

Pares-Sierra, A., and G. K. Vallis, 1988: A fast semi-direct method for the numerical solution of non-separable elliptic equations in irregular domains. J. Comp. Physics, 82, 398-412.

Vallis, G. K., G. F. Carnevale, and W. R. Young, 1989: Extremal energy properties and construction of stable solutions of the Euler equations. J. Fluid Mech., 203, 133-152.

Carnevale, G. F., and G. K. Vallis, 1989: Pseudo-advective relaxation to stable two-dimensional states. J. Fluid Mech., in press.

Auad, G., A. Pares-Sierra, and G. K. Vallis, 1990: The energetics and mean flow of an eddy resolving model of the California Current. (shortly to be submitted to J. Phys. Oceanogr.)

Holland, W., and G. K. Vallis, 1990: Nested models of the ocean circulation: an application to the California Current. (shortly to be submitted to J. Phys. Oceanogr.)

Pares-Sierra, A., 1990: On the equatorial origin of some of the Rossby wave activity in the Midlatitude Pacific Ocean. J. Geophys. Res., in press.

Pares-Sierra, A., and J. J. O'Brien, 1990: The seasonal and interannual variability of the California Current System: a numerical model. J. Geophys. Res., in press.

UNIVERSITY RESEARCH INITIATIVE
Final Report
March, 1990

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1. SUMMARY OF RESEARCH ACTIVITY

Over the past twelve months, real GEOSAT altimetric sea level differences collected over the first one year-period of the Exact Repeat Mission (ERM), from November 1986—October 1987, have been assimilated into a wind driven realistic quasi-geostrophic numerical model of the California Current, following from the necessity of gridding these data onto a regular grid from an irregular grid (i.e., the ascending and descending tracks of the GEOSAT altimeter) in such a way that the interpolated sea level information is dynamically consistent (White *et al.*, 1990c). This so-called dynamical interpolation has been found to have numerous advantages over statistical interpolation employed earlier in the gridding of altimetric sea level data (e.g., White *et al.*, 1990a; White *et al.*, 1990b): i.e., it allows mesoscale eddy features to propagate between repeat-tracks of the altimeter without artificial reduction in magnitude; hence, it allows the wavenumber/frequency content of the mesoscale eddy activity to be more faithfully represented; it allows more observational information (e.g., wind stress curl) than just altimetric sea level differences to be brought to bear upon the interpolation of sea level; it allows both the barotropic and the internal baroclinic modal structure to be detected from sea level information alone; and it allows the resulting interpolated fields to be analyzed for their dynamical content (i.e., computing realistic estimates of vorticity and kinetic energy budgets). These dynamically interpolated altimetric sea level estimates were compared with *in situ* estimates of sea level computed from XBT observations, showing near perfect ability of the altimeter in specifying the annual and semi-annual cycles of mesoscale eddy activity in the California Current.

In past efforts, continuous model/data assimilation was conducted in a **nowcast** mode, where only data from the past were used to determine the present state; as such, it represented a test of the methods to be used in future **nowcast** operations using real-time altimetric sea level data. However, more recently continuous model/data assimilation was conducted in a **forecast** mode, allowing real-time altimetric altimetric sea level data to be used in a **forecast** of the mesoscale eddy activity in the California Current 2-3 weeks in advance of present time (White *et al.*, 1990c).

2. LIST OF PUBLICATIONS

Pares-Sierra, A., W.B. White, and C.-K. Tai, 1990. On the mesoscale variability in the California Current region: a model-satellite intercomparison. *J. Geophys. Res.*, (in review).

White, W.B., C.-K. Tai, and J. DiMento, 1990. Annual Rossby wave characteristics in the California Current region from the GEOSAT exact repeat mission. *J. Geophys. Res.*, (in review).

White, W.B., C.-K. Tai, and W.R. Holland, 1990a. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model: (Part 1) Sea level differences. *J. Geophys. Res.*, (in press).

White, W.B., C.-K. Tai, and W.R. Holland, 1990b. Continuous assimilation of simulated GEOSAT altimetric sea level into an eddy resolving numerical ocean model: (Part 2) Referenced sea level differences. *J. Geophys. Res.*, (in press).

White, W.B., C. K. Tai, and W.R. Holland, 1990c. Continuous assimilation of GEOSAT altimetric sea level observations into a numerical synoptic ocean model of the California Current system. *J. Geophys. Res.*, (in press).

3. COOPERATION WITH NAVY LABORATORIES

The latest research is in support of developing an experimental prediction capability for the synoptic mesoscale circulation of the upper ocean on a regional basis in the California Current. This involves both **nowcasting** and **forecasting** in the California Current. This effort has been proposed to the operational Navy (NOARL) for the three-year period following the termination of the University Research Initiative; presently, this effort is being supported by both CalSpace and ENCORE at the University of California at San Diego. Collaboration is ongoing with Drs. Jim Mitchell, Harley Hurlburt, Dana Thompson, and Donna Blake at NOARL at the Stennis Space Center in Bay St. Louis, MS, applying the continuous model/ data assimilation software to global and regional primitive equation eddy resolving prognostic models.

Already, considerable progress has been made in describing and understanding the mesoscale eddy activity in the California Current through the simultaneous examination of both *in situ* and remotely-sensed data (White *et al.*, 1990c). This has lead, recently, to the development of a realistic primitive equation, wind driven, eddy-resolving prognostic model of the California Current, to be used in this effort, developed by Pares-Sierra and Vallis (1989) at SIO under the University Research Initiative.

This realistic model of the California Current is an extension of the 1-1/2 layer wind driven FSU model developed for the California Current region by Pares-Sierra and O'Brien (1989). The present version of this model has been extended to 10 km resolution, with additional layers that allow baroclinic instability to exist in the model; moreover, it was possible to include the effects of bottom bathymetry on the synoptic circulation of the California Current. This model is driven by the synoptic wind stress computed from the synoptic wind analysis of FNOC. This wind-driven model reproduces much of the mean and statistical aspects of the synoptic mesoscale circulation in the California Current. An assimilation package, called "UPDATE" will be used with this model in the assimilation of GEOSAT ERM altimetric sea level into the model, thereby defining the phase of the mesoscale eddy activity in the model synoptic California Current.

Altimetric sea level data from the GEOSAT Exact Repeat Mission (ERM) must have extensive pre-processing applied to it before it can be assimilated into the prognostic model. A part of this pre-processing requires both the mean and the long wave portion of the data (along track) to be removed, yielding residual, high-passed, estimates of the altimetric sea level. Yet before assimilation into the model, these residuals must be referenced to a new mean and the long wave portion of the observations restored. This referencing is accomplished by using the mean and long wave information along track from the model itself. These referenced sea level residuals, as they become available in real time, are then combined with the model sea level after each time step in the model integration, with the latter seen to be updated by the former. This updating procedure occurs following the formalism of optimal interpolation used in meteorology (Lorenc, 1981).

The specific experimental products to be computed in real time (i.e., within a week of the present day) are tentatively given as follows, subject to change depending upon the needs of the users:

1. Horizontal distribution of surface dynamic topography;
2. Horizontal distribution of subsurface dynamic topography at standard levels in the upper 500 m;
3. Offshore vertical sections (extending to 500 m) of along-shore currents at standard CalCOFI lines;
4. Offshore vertical sections (extending to 500 m) of the anomalous baroclinic structure at standard CalCOFI lines.

These weekly experimental products will be disseminated on a monthly basis to those interested scientists and institutions. Verification of the experimental products will be conducted in a hindcast mode initially, establishing that the model/data assimilation compares with *in situ* observation to within a specified error; this will be established before the first experimental products are put "on line". It is expected that critical review by the users of these experimental products will be important in their improvement.